The Fauna of Careel Bay with Comments on the Ecology of Mangrove and Sea-Grass Communities

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ABSTRACT

Careel Bay, Pittwater, New South Wales can be divided into five zones, salt marsh, mangroves, *Zostera* and *Posidonia* weed beds and sandy beach. The flora and fauna of each of these zones are described with comments on the seasonal abundance of animals in the weed beds and on the sandy beach. Finally the inter-relationship of these zones to each other especially in relation to the detritus food chain is discussed.

INTRODUCTION

It is widely accepted that salt marsh, mangrove and sea-grass communities are important components of estuarine ecosystems (Lyford and Plinney, 1968; Odum, 1961; Odum and de La Cruz, 1967. These communities act as nurseries for many organisms and produce large quantities of organic matter which forms the base of estuarine food chains. These communities have been little studied in Australia (Clarke and Hannon, 1967, 1969, 1970, 1971; Collins, 1921; Goodrick, 1970; Hamilton, 1919; Kratochvil, Hannon and Clarke, 1972; Macnae, 1966, 1967) and even basic descriptions of fauna are lacking.

During 1972, the New South Wales Division of the Australian Littoral Society surveyed the biology of Careel Bay in Pittwater on the Central Coast of New South Wales (Hattersley, Hutchings and Recher, 1973). The survey considerably expanded our knowledge of the fauna of estuarine habitats on the Central Coast, but in view of the limited data available for the fauna of mangrove and sea-grass communities in Australia, it was decided to extend the survey for an additional year. The results of the work during 1972 and 1973 are presented in this paper and although emphasis is on a description of the fauna, its distribution within Careel Bay and seasonal changes, the role of salt marsh, mangrove and sea-grass communities in the ecology of the estuary is also considered.

Careel Bay

Careel Bay (33° 37′ S; 151° 20′ E) is situated on the southeastern shore of Pittwater. Pittwater is part of the Hawkesbury River-Broken Bay estuary (Fig. 1): an extensive drowned river valley 32 km north of Sydney. No major

river flows into Pittwater and it is unlikely that any significant amount of freshwater reaches Pittwater from the Hawkesbury River. The volume of fresh water coming down the Hawkesbury River is irregular and carries a heavy silt load. At times of flood on the Hawkesbury we have not observed any intrusion of river water into Pittwater or Careel Bay.

Development on the watershed of Pittwater is primarily residential with substantial areas along the northern shores reserved as National Park. Careel Bay is shallow, but well protected from prevailing winds. Surrounding lands have been developed for residential purposes and water flowing into the Bay

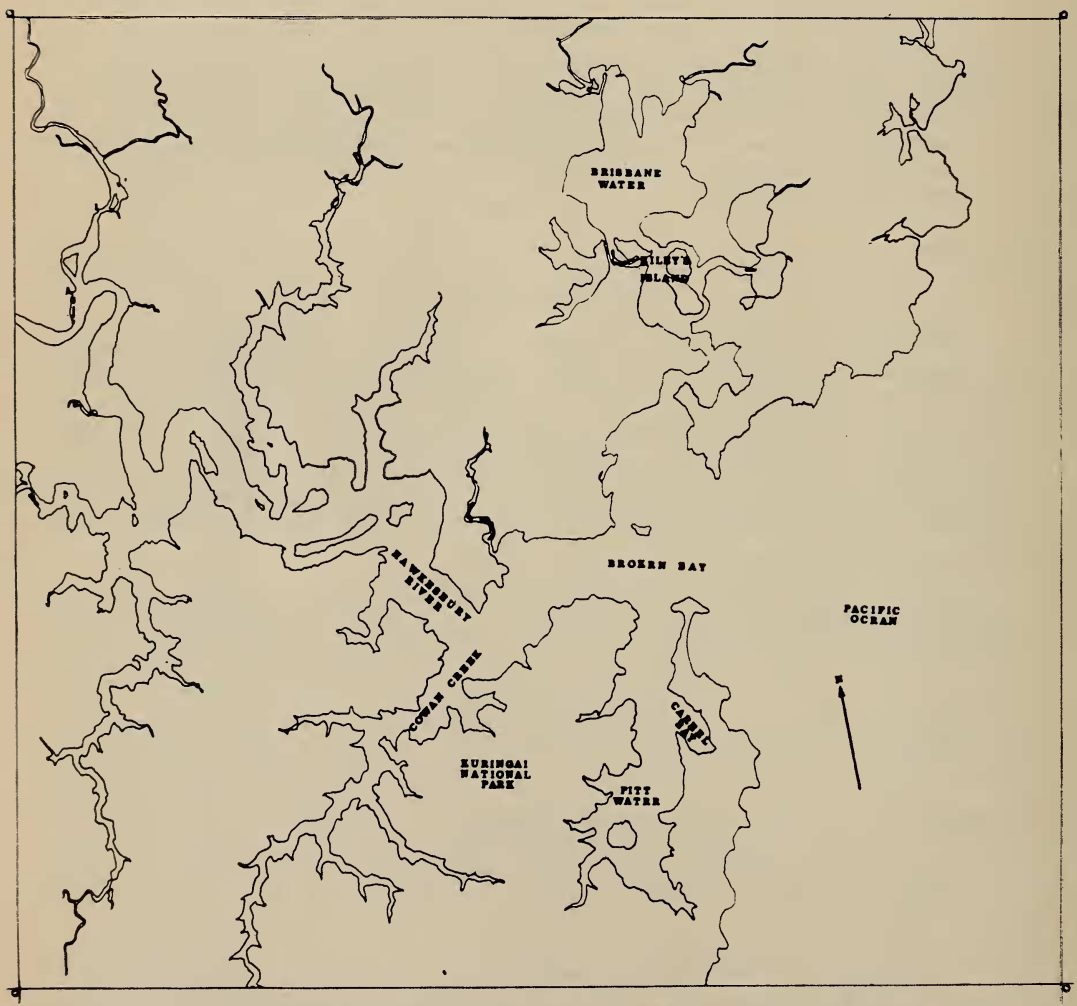


Fig. 1. Map of Pittwater, Hawkesbury River and Brisbane Waters, showing the relationship of Careel Bay to these areas.

comes primarily as runoff from the storm water drainage system. There is some seepage from septic systems and runoff from the garbage tip. Other than minor local effects, water pollution, however, is not a problem. The Bay opens widely to Pittwater and the tidal range is 2 m. The entrance to Careel Bay is marked by a sand bar which consists of sediments transported from the ocean side of Pittwater. The bar prevents sand from entering the Bay, but does not seem to impair the exchange of water with Pittwater. Sediment deposition is occurring at the head of Careel Bay and over the last century, 1.3m of sediment has been deposited (Hattersley, Hutchings and Recher, 1973). The mangroves and sea grass flats at the head of the Bay appear to trap and retain most of these sediments. It is likely that these sediments have been derived from disturbances associated with the residential development of the foreshores and surrounding areas and the rate of sedimentation may decline when the area is fully developed.

TABLE 1

AREA OF MAJOR LITTORAL HABITATS

Zone	Area (m^2)	%
Sandy beach	149.0	15
Salt marsh	32.9	3
Mangroves	82.9	7
Zostera Sea grass flats	427.5	38
Posidonia Sea grass flats	410.0	37

The estuarine environment of Careel Bay (Fig 2) can be conveniently divided into five zones, sandy beach, salt marsh, mangrove (Fig. 3), *Zostera* grass flats and *Posidonia* grass flats. The extent of each zone is given in Table 1. The zones and their approximate distributions are shown in Fig. 4.

METHODS

Between January 1972 and December 1973 a number of general collecting trips were made to Careel Bay. These included night collecting. A representative sample of all the animals collected during this survey has been deposited in the Australian Museum, Sydney. In addition quantitative sampling was carried out in February, June and November, 1973. In February only the upper zone of *Zostera* was sampled, but in June and November the upper and lower zones were sampled separately.

During each period of quantitative sampling ten samples were collected from the *Posidonia* and *Zostera* weed beds and sandy beach. Using a spade 9000 cm^3 of

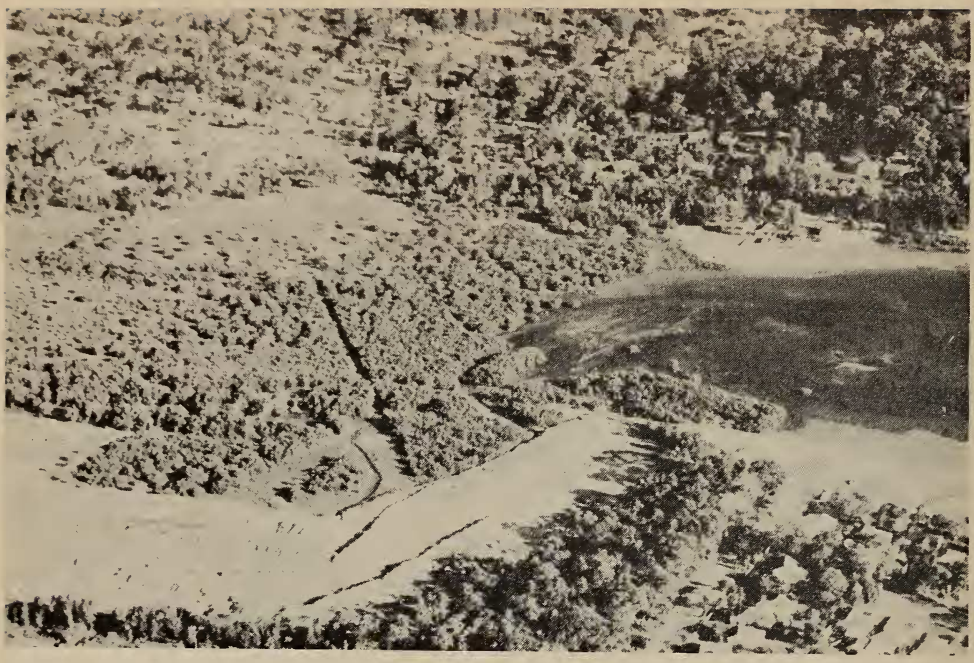


Fig. 2. Aerial photograph of Careel Bay. Photo: Peter Whalan.

Fig. 3. The salt marsh mangrove junction. Numerous small bushes of *Avicennia marina* in the foreground, amongst the salt marsh vegetation. Photo: Peter Whalan.

mud or sand and associated plants (if any) was collected and passed through a 2.0 mm sieve. In taking the samples, only the surface layer of the substrate to a depth of 10 to 20 cm was collected. Fast swimming and deep burrowing animals were probably missed or underestimated by this method. In the *Posidonia* zone, a different method was adopted for the June and November samples. Divers with SCUBA pulled out plants with their root systems and adhering mud until 9000 cm^3 of material had been collected. Again 10 samples were collected, but these are not comparable with the samples taken in January or from the other zones. We found collecting in the *Posidonia* difficult and this zone was not well sampled.

In addition to the volumetric samples, the population density and size distribution of the Sydney cockle *Anadara trapezia* was measured using a 0.25m^2 quadrat in the lower *Zostera*. A 0.25m^2 quadrat was used also to estimate the biomass of *Zostera* and *Posidonia*. The quadrat was placed randomly ten times in each zone and all plant material was removed from within the quadrat. The plants were washed, excess moisture and epiphytes removed and the plants weighed. The samples were then dried at a constant humidity and temperature (21°C) ad re-weighed until constant weight.

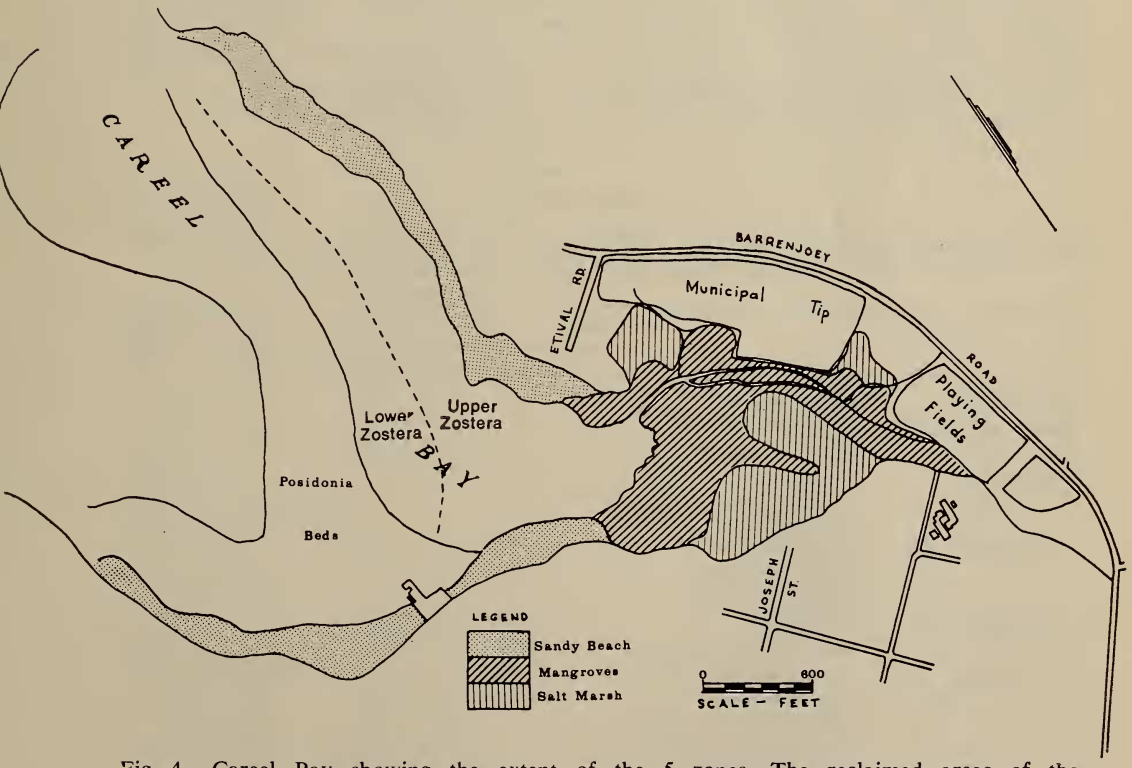


Fig. 4. Careel Bay showing the extent of the 5 zones. The reclaimed areas of the Municipal Tip and Playing Fields are also shown.

FAUNA

The fauna of Careel Bay will be presented in two ways. First we describe the major groups of animals which occur in Careel Bay. Second we relate the distribution and abundance of the fauna to each of the five major habitats (zones) in Careel Bay.

Marine Invertebrates

A list of the marine invertebrates collected during 1972 and 1973 at Careel Bay is presented in Table 2. This table also shows the distribution of species by zones and an indication of species abundance on a scale of $\log_e$ throughout the year. Absolute values of abundance are not given as we have insufficient quantitative data for most animals to justify giving precise figures. Also some of the species are very patchy in their distribution. The *Zostera* has been considered as a single zone in this Table. The faunal lists for the five zones present in Careel Bay are not complete, as even after 2 years of regular collecting, new records for the Bay continue to be obtained. These probably represent seasonal visitors to the Bay or species which are sparsely represented in the Bay. The species list for the mangrove zone is incomplete in that the infauna of the mud was inadequately sampled. For practical reasons it was only possible to sample areas adjacent to the creek. Other invertebrates occur in Careel Bay such as encrusting organisms on pilings, moorings or rocky habitats, and these were not sampled during this survey.

TABLE 2

DISTRIBUTION AND ABUNDANCE (WHERE AVAILABLE) ON A SCALE $\log_e$ OF MARINE INVERTEBRATES IN CAREEL BAY

		Salt marsh	mangroves	Zostera	Posidonia	Sandy beach
Coelenterates	*Edwardsia* sp.			1	1	
Platyhelminthes	Turbellarian			1		
Nemerteans	Heteronemertean			2	2	1
Polychaetes						
F. Polynoidae	*Paralepidonotus cf. ampuliferons*			1	1	
F. Phyllodocidae	*Phyllodoce novaehollandiae*			1		
	Phyllodoce sp.			1		
F. Syllidae	*Syllis* sp. 1			1	1	
	Syllis sp. 2			1		
F. Nereidae	*Australonereis ehlersi*			1		4
	Ceratonereis erythraeensis	1		1		
	Ceratonereis mirabilis			1		
	Neanthes vaalii		1	1		
	Nereis (Hediste) diversicolor		1	3		1

TABLE 2 (continued)

		Salt marsh	mangroves	Zostera	Posidonia	Sandy beach
F. Nephtyidae	*Nephtys australiensis*		1	4	1	1
F. Glyceridae	*Glycera americana*			1	2	
F. Eunicidae	*Marphysa sanguinea*			1	1	
F. Lumbrineridae	*Lumbrineris latreilli*			1	1	
F. Orbiniidae	*Haploscoloplos* n. sp.		1	1	1	3
	Naineris sp.				1	
	Orbinia sp.			1	1	
	Phyllo sp.			1	1	
	Scoloplos sp.			1		
F. Spionidae	*Boccardia* sp.	1				
	Dispio sp.				1	
	Malacoceros sp.				1	
	Polydora sp.		2	2	1	1
	Prionospio sp.			1	2	
F. Magelonidae	*Magelona* sp.			1		1
F. Chaetopteridae	*Chaetopterus* sp.			1	1	1
F. Cirratulidae	*Cirratulus* sp.					1
F. Flabelligeridae	*Pherusa* sp.				1	
F. Opheliidae	*Armandia lanceolata*			1	1	
F. Capitellidae	*Barantolla lepte*			3	1	1
	Capitella capitata	1		1		1
	Heteromastus sp.				1	
	Mediomastus sp.			1	1	
	Notomastus hemipodus			5	2	
F. Maldanidae	—incomplete specimen			1		
F. Arenicolidae	*Arenicola bombayensis*			1		
F. Oweniidae	*Owenia fusiformis*			3	1	1
F. Ampharetidae	*Amphicteis* sp.			1		
	Lysippides sp.				1	
	Samytha sp.			1		
F. Terebellidae	*Lysilla pacifica*			2	1	
	Thelepus setosus				1	
	Rhinothelepus lobatus			2	1	
	Pista sp.			1		
F. Serpulidae	*Spirorbis* sp.			3	3	
	Hydroides sp.				1	
Phoronids	*Phoronis* sp.			1		
Crustaceans						
Sub-Class. Cirripedia						
F. Balanidae	*Balanus amphitrite*		1			
Order Isopoda						
F. Anthuridae					1	
F. Sphraeromidae	*Cymodoce coronata*				1	
F. Ligidae	*Ligia australiensis*		x		1	
Order Amphipoda						
F. Ampithoidae	*Ampithoe* sp.		x	2	2	
F. Gammaridae	*Melita* sp.			2		
F. Liljeborgidae	*Liljeborgia* sp.				1	
F. Haustoriidae	*Urohaustorius* sp.				1	1

TABLE 2 (continued)

			Salt marsh	mangroves	Zostera	Posidonia	Sandy beach
Order Decapoda							
F. Penaeidae	*Penaeus plebejus*			x	2	2	1
	Penaeus esculentus				1	1	
	Penaeus sp.				1		
F. Palaemonidae	*Macrobrachium intermedius*					1	
F. Alpheidae	*Alpheus euphrosyne*				2	2	
	Alpheus sp. B				1	1	
	Alpheus sp. C				x		
F. Hippolytidae	*Hippolyte tenuirostris*					1	
F. Laomediidae	*Laomedia healyi*			x			
F. Callianassinae	*Callianassa* sp.				1	1	2
F. Paguridae					x		
F. Hymenosomatidae	*Halicarcinus ovatus*					1	
F. Portunidae	*Portunus pelagicus*				1	1	
	Thalamita sima				1	1	
	Thalamita crenata				x		
	Scylla serrata			x			
F. Xanthidae	*Heteropanope serratifrons*				1	1	
F. Grapsidae	*Sesarma erythrodactyla*		x	x			
	Paragrapsus laevis		x	x			
F. Ocypodidae	*Heloecius cordiformis*		x	x			
	Macrophthalmus setosus			x	2		
	Macrophthalmus crassipes				2		
	Macrophthalmus cf *punctulatus*				x		1
	Macrophthalmus sp. 1				x		1
	Macrophthalmus sp. 2				x		x
	Species A				2		
	Species B				1		1
	Australoplax tridentata			x	x	1	
F. Mictyridae	*Mictyris longicarpus*				x		3
Molluscs							
F. Arcidae	*Anadara trapezia*			x	3	x	
F. Mytilidae	*Modiolus pulex*			x	x		
	Mytilus edulis				x		
	Xenostrobus securis				1		
F. Laternulidae	*Laternula tasmanica*				1		
F. Lodabiidae	*Cavatidens omissa*				2	1	1
F. Leptonidae	*Mysella* sp.				1	1	
F. Ostreidae	*Saccostrea cucullata*			x			
F. Veneridae	*Eumarcia fumigata*				1		1
	Tapes watlingi				1		1
F. Macturidae	*Notospisula parva producta*				2	1	2
F. Garidae	*Florisarka onuphria*						1
F. Tellinidae	*Macoma deltoidalis*				2	2	1
F. Teredinidae	*Teredo* sp.			x			
F. Trochidae	*Austrocochlea obtusa*		x	x	1		
	Calliostoma australe			x		1	
	Salsipotens meyeri			x			
F. Liotidae	*Liotia* sp.				1		

TABLE 2 (continued)

		Salt marsh	mangroves	Zostera	Posidonia	Sandy beach
F. Acmaeidae	*Chiazacmea flammea*		x			
F. Neritidae	*Nerita atrementosa*			x		
F. Littorinidae	*Littorina scabra*		x	x		
	Bembicium auratium	x	x	1		
F. Dialiidae	*Diala* sp.				1	
F. Tateidae	*Tatea rufilabris*	x				
F. Cerithidae	*Cacozeliana lacertina*			1	2	1
F. Potamiidae	*Pyrazus ebenensis*			1		
	Velacumantus australis		x	1		
F. Epitoniidae	*Epitonium* sp.			1		
F. Naticidae	*Conuber sordidum*			1		1
	Conuber sp.					1
F. Nassariidae	*Nassarius burchardi*		x	1	1	1
	Nassarius jonasi			x		
F. Muricidae	*Bedeva hanleyi*				1	1
F. Pythidae	*Melosidula zonata*	x				
	Ophicardelus sulcatus	x	x			
	Ophicardelus ornatus	x				
	Ophicardelus quoyi	x	x			
F. Amphibolidae	*Salinator solida*	x				
	Salinator sp.					1
F. Onchidiidae	*Onchidium damelli*		x	x		
F. Akeridae	*Haminoea wallissi*			2		
F. Aplysidae	*Aplysia dactylomela*			x	x	
	Aplysia juliana			x	x	
F. Elysiidae	*Elysia australis*			x	x	
F. Doridiidae				1		
F. Sepiolidae	*Euprymna stenodactyla*			x	x	
Echinoderms	*Astropecten polycanthus*			x		
Ascidian	*Botrylloides nigrum*				x	

The sea anemone *Edwardsia* sp. and an unidentified turbellarian were collected in the upper *Zostera* zone. A single species of heteronemertean was collected from the sandy beach, *Zostera* and *Posidonia* zones. This species is being described by Gibson (Liverpool Poly., U.K.).

Forty-six species of polychaetes representing 22 families were collected including 21 identified to species level. Many of the polychaetes are new records for New South Wales and some undescribed species are present. These will be described in a paper by Hutchings (in prep.). No species of polychaete was found throughout the Bay although *Haploscoloplos* n. sp. was found in all zones except the salt marsh (Table 2). Twenty-three species occurred in two or three zones while 19 species were confined to a single zone. The *Zostera* weed beds had the richest fauna of polychaetes many of which are tubiculous including the abundant nereid *Australonereis ehlersi*. The salt marsh, mangroves and sandy

beach had few species present although some in the sandy beach (e.g. *Australonereis ehlersi* and *Haploscoloplos* n. sp.) were abundant. A phoronid was found living in the empty tubes of the polychaete *Owenia fusiformis,* in November, 1973.

The majority of the polychaetes found in Careel Bay are detritus feeders. Some like *Arenicola* and all the capitellids actively ingest the substrate and digest the algae and bacteria adhering to the surface of the mud particles. Newell (1965) and Longbottom (1968) have shown how the resulting faecal material is enriched with nitrogen compounds which are then utilized by the bacteria and algae in the sediment. Subsequently this sediment is re-ingested and the cycle is repeated. The terebellids are surface deposit feeders, (Dales, 1955). Other species of polychaetes present are filter feeders, feeding on suspended detritus material and phytoplankton, these include *Chaetopterus,* and the serpulids. It is likely that *Nephtys australiensis* and many of the nereids are omnivorous scavengers although some experimental work has indicated that the polynoid *Paralepidonotus* cf. *ampuliferons,* the glycerid *Glycera americana* and the syllids are probably active carnivores feeding on small worms and crustaceans (pers. obser.).

Thirty-eight species of crustaceans were recorded from Careel Bay, most of these (31) occurred in the *Zostera* and *Posidonia* zones with only eight species present on the sandy beach. Three species occurred in the salt marsh and eleven species among the mangroves. Amphipods, isopods and other smaller crustacea were poorly sampled.

Many of the larger crustaceans were extremely abundant and show precise patterns of zonation with reference to high and low water marks. On the sandy beach a new species of *Callianassa* has been found and this is being described by Poore (Fisheries & Wildlife, Victoria, Australia). Three species of the snapping prawns *Alpheus* sp. were present in the weed beds and these are being described by Banner (Hawaii). Two crabs species, A & B, as yet unidentified, were especially abundant in the lower *Zostera,* but also occurred in the upper *Zostera* zone. Species A (Table 2) may be *Camptandrium paludicola* a species recorded by Snelling (1959) from the Brisbane River, Queensland. Three species of penaeid and carid prawns, *Penaeus plebejus* and *P. esculentus* and *Macrobrachium intermedius* were very abundant in the weed beds.

Many of the crabs in the mangroves feed on the algae growing on the bases of the mangrove trees and pneumatophores. Large numbers of crabs were observed feeding at night during low tide. For example *Paragrapsus laevis* was present in numbers ranging from 24-30 individuals /m^2, *Sesarma erythrodactyla* varied from 13-88/m^2, *Heloecius cordiformis* 3/m^2 and *Australoplax tridentata* 9/m^2. Similar measurements made during the day at low tide were in the order of 10-15 crabs/m^2. The amphipods, *Callianassa* and the alpheids are predominantly detritus feeders; and the soldier crab *Mictyris longicarpus* ingests the sand removing organic material.

Forty-six species of molluscs were collected during the survey. Gastropods were the most numerous (31 species) followed by pelecypods with 14 species. We did not collect any chitons (Placophora), but they occur at Careel Bay along the rocky foreshores. Two species of cephalopods occur, *Octopus cyaneus* and *Sepia* sp., (Dakin, Bennett and Pope, 1952), but were not collected in this survey. The opisthobranchs, *Aplysia dactylomela* and *Aplysia juliana,* were particularly abundant during the spring and early summer on the sea grass flats. In contrast to the polychaetes, many of the molluscs were confined to a single zone. No species occurs in more than three of the five zones.

The molluscs can be divided into two main feeding categories, filter feeders and grazers. The bivalves which would represent the greatest biomass amongst the molluscs are all filter feeders; these are present in all zones except the salt marsh. In the weed beds, common species are *Anadara trapezia, Macoma deltoidalis* and in the mangroves *Saccostrea cucullata.* The grazers are represented by the gastropods, which feed either on the film of epibiota on the surface of the sea grasses or on the surface of the mud in the salt marsh or mangroves.

The only other marine invertebrates collected during the survey were the burrowing starfish *Astropecten polycanthus* in the lower *Zostera* and *Posidonia,* and the compound ascidian *Botrylloides nigrum.* This ascidian was found encrusting the leaves of the *Posidonia* in the November samples.

TABLE 3

SPIDER FAUNA OF CAREEL BAY

Order. Araneae		Salt Marsh	Mangroves
F. Clubionidae	*Clubiona robusta*		x
	Miturga sp.	x	
F. Pisauridae	*Dolomedes facetus*		x
F. Lycosidae	*Anoteropis longipes*	x	x
	Lycosa furcillata		x
	Lycosa sp.	x	x
F. Hersiliidae	*Tama novaehollandiae*		x
F. Thomisidae	*Diaea* sp.	x	
F. Theridiidae	*Argyrodes antipodianus*		x
F. Tetragnathidae	*Tetragnatha bituberculata*		x
	Tetragnatha sp.	x	
F. Argiopidae	*Aranea insuta*	x	x
	Aranea sp.		x
	Argiope aethera	x	
	Nephila ornata		x
F. Linyphiidae	*Erigoninae* sp.	x	x
	Laetesia sp.	x	
	Linyphiinae sp.		x

Many of the spiders identified only to genus are juveniles.

Non Marine Invertebrates

A list of the spiders collected during the survey is presented in Table 3. Many species were collected only once and information on the seasonal occurrence of species is not available. Many of the spiders were identified to genus only as they were juveniles. In Appendix I, a list of insects which have been recorded from Careel Bay is given, this was compiled by D. McAlpine and G. Holloway of the Australian Museum from their Departmental records. Two interesting flies of the tropical genera *Merodonta* and *Pemphigonotus* have been found in the Bay and constitute new southern records for the genera. *Chelonus unimaculatus* and *C. australiensis* have been recorded for the first time since their original description in 1905. The larvae of the mangrove plume moth *Cenoloba obliteratis* which are restricted to the fruit and young shoots of *Avicennia marina* were present. Also present is the mangrove fruit fly *Euphranta* sp. which is restricted to mangrove habitats as its larvae live in the fruits of *A. marina.*

TABLE 4

WADING AND SEA BIRDS OF CAREEL BAY
(species which occur regularly)

White-faced Heron	*Ardea novaehollandiae*
Mangrove Heron	*Butorides striatus*
White Egret	*Egretta alba*
White Ibis	*Threskiornis molucca*
Straw-necked Ibis	*Threskiornis spinocollis*
Black Billed Spoonbill	*Platalea regia*
Yellow Billed Spoonbill	*Platalea flavipes*
Little Pied Cormorant	*Phalacrocorax melanoleucos*
Australian Pelican	*Pelecanus conspicillatus*
Black Cormorant	*Phalacrocorax carbo*
Black Duck	*Anas superciliosa*
Dusky Moorhen	*Gallinula tenebrosa*
Grey Teal	*Anas gibberifrons*
Spur Winged Plover	*Vanellus miles novaehollandiae*
Bar-tailed Godwit	*Limosa lapponica*
Eastern Curlew	*Numenius madagascariensis*
Whimbrell	*Numenius phaeopus*
Red-necked Stint	*Calidris ruficollis*
Grey tailed Tatler	*Tringa brevipes*
Southern Stone Curlew	*Burhinus magnirostris*
Sacred Kingfisher	*Halcyon sancta*
Azure Kingfisher	*Alcyone azurea*
White Breasted Sea Eagle	*Haliaetus leucogaster*
Whistling Kite	*Haliastur sphenurus*
Silver Gull	*Larus novaehollandiae*
Crested Tern	*Sterna bergii*
White Fronted Tern	*Sterna striata*

Marine Vertebrates

Two groups of marine vertebrates need to be considered; fish and birds. Both groups are conspicuous and important parts of the Bay and the Hawkesbury River-Broken Bay estuary. Indeed, in the context of immediate social concern and economic value, both groups are of special interest. It is difficult to sample either group quantitatively and our observations are necessarily qualitative. Birds and fish are highly mobile animals and changes in numbers and species composition occur with each tide and season.

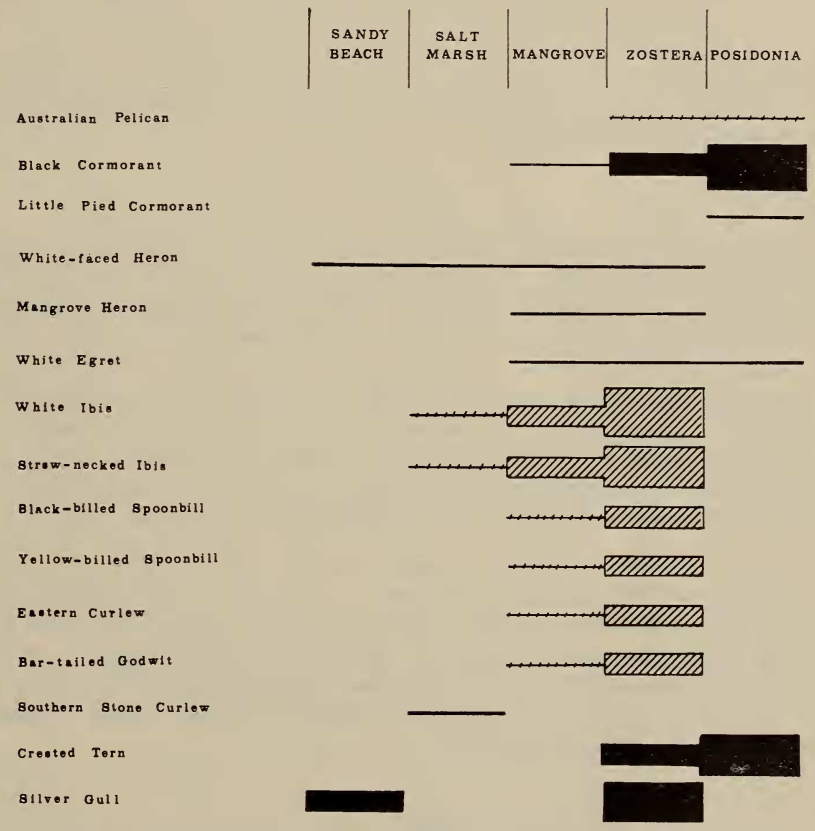
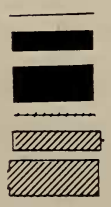


Fig. 5. Schematic diagram showing the abundance and feeding zones of the common Careel Bay Birds.



nos. of birds of species always present in the Bay.

nos. of birds of species often present in the Bay.

a. *Fish*

Fish were sampled using a 8 m seine with a fine 6 mm mesh. Thus, small fish and juveniles rather than large fish were taken. The grass flats of Careel Bay supported large numbers of young fish of commercially important species. For example, numerous juveniles of trevally, blackfish, bream, tarwhine, whiting and leather jackets were taken. These fish depend on the shallow waters of the estuary for their early growth and survival. Other species are resident on the grass flats and among the mangroves. Some, such as mullet, form important parts of the estuarine food chain and channel the organic production of the sea grasses and mangroves into larger and economically important species (Odum and Heald, 1972). A list of fishes collected in Careel Bay and elsewhere in the Hawkesbury system are presented in Appendix II; all the species listed are expected to occur in Careel Bay.

b. *Birds*

The estuarine food chains which begin with the sea grasses and mangroves often terminate with birds. At Careel Bay, wading and diving birds are a conspicuous part of the fauna (Table 4). Wading birds forage on the sea grass flats and among the mangroves at low tide while others such as terns, cormorants and pelicans feed when the flats are covered by water. The *Zostera* zone is the most important feeding area for the birds at Careel Bay and relatively few forage in the mangroves or on the salt marsh. However, the mangroves and salt marsh are important refuges at high tide and the mangroves provide nesting sites for herons. The salt marsh at Careel Bay is one of two places on the Central Coast where the Southern Stone Curlew *Burhinus magnirostris* nests.

In Fig. 5 we have shown the most common birds recorded at Careel Bay during 1972 and 1973 and the habitats in which they fed. Birds are highly mobile animals and their numbers tend to fluctuate with tide, weather and seasonal conditions. Probably most of the birds which forage on the tidal areas of Careel Bay range widely throughout the Hawkesbury River-Broken Bay estuary. In Fig. 5, we have, therefore, given relative numbers based on consistency of occurrence and absolute numbers.

HABITATS

Sandy Beach

The beach is made up of coarse clean sand. Some sediment and freshwater is carried onto the beach by a storm water drainage channel which empties directly on the beach. The beach gradually merges into the *Zostera.* On the land side of the beach there is limited development of *Juncus maritimus* and *Salicornia quinqueflora.* Residential development adjoining the beach has limited the area occupied by these plants.

Polychaetes were the most abundant and diverse group of invertebrates found in this zone. The most abundant species were *Australonereis ehlersi* and *Haploscoloplos* n. sp., both of which bred successfully during the year. This was indicated by their increase in numbers per sample due to the settlement of juveniles (Table 6). *Haploscoloplos* n. sp. bred between June and November and juveniles were abundant in the November sample. There was no evidence of mass mortality of the adults occurring after breeding. *Australonereis ehlersi* bred earlier in the year; in the June sample, numerous newly settled individuals were present, suggesting breeding had begun in April or May. Breeding was still occurring in June as many of the females were gravid. Juveniles were present in November samples. It is not known whether breeding occurred continually throughout this period or if there were distinct outbursts of spawning, as found in many nereids (Clark, 1965; Schroeder, 1968). Hartman (1954) suggests *A. ehlersi* may be viviparous no evidence of this was found. The numbers present in November are greater than those found in the preceding February suggesting that either 1972 was a less successful breeding season than 1973 or that many of the spawned worms will die during the subsequent summer months. Most species of nereids which have been studied breed once and then die (Clark, 1961; Dales, 1950).

The soldier crab *Mictyris longicarpus* was the most abundant crustacean in the sand, and newly settled individuals were numerous in June and November samples. The juvenile stages were more easily sampled by our methods than the adults and appear more abundant in our samples. Nevertheless, Careel Bay has a large population of adult soldier crabs. All other crustaceans were sparsely represented in the samples (Table 6).

Notospisula parva producta was the most abundant mollusc present in this zone and numbers increased in June due to the settlement of juveniles between February and June. Many of the other molluscs were represented only by one or two individuals e.g. *Eumarcia fumigata, Cacozeliana lacertina* and *Macoma deltoidalis.* A single juvenile of *Salinator* sp. was found in June.

Salt Marsh

The salt marsh occupies the area between the mangroves and fully terrestrial habitats. This zone has been affected by land fill operations and was probably bordered originally by paperbarks *Melaleuca* sp. and she-oak *Casuarina glauca.* The terrestrial margin of the salt marsh is dominated by the sedges, *Cyperus polystachyos* and *Juncus maritimus* var. *australiensis,* among which are scattered *Casuarina glauca.* Between the sedge zone and the mangroves is a region with bare mud and a patchy vegetation of *Salicornia quinqueflora* and *Triglochia striata.* Towards the mangroves there is a scattering of stunted mangroves *Avicennia marina* (Fig. 3). The patchy distribution of *Salicornia, Triglochia* and *Avicennia* in this zone reflects different levels of soil moisture and soil salinity (Clarke and Hannon,

Fig. 6. Inside the mangroves, looking towards the weed beds. Photo: Dan Lunney.

Fig. 7. The upper *Zostera* weed beds. In the foreground are numerous seedlings of *Avicennia marina*. Photo: Dan Lunney.

1967, 1969, 1970, 1971). The mangroves for instance, invariably occupy depressions in the substrate surface.

The marine invertebrate fauna of the salt marsh was limited but the species present were usually represented by large numbers of individuals. The gastropods *Salinator solida* (1080/m^2), *Tatea rufilabris* (74/m^2), *Ophicardelus sulcatus* (264/m^2) and *O. quoyi* (217/m^2) were the most abundant molluscs present. These animals were found on the surface of the mud, and were closely associated with the vegetation. The crabs *Sesarma erythrodactyla, Paragrapsus laevis* and *Heloecius cordiformis* were also common, especially in wetter areas.

Polychaetes appear to be entirely restricted to the mangrove margin of the salt marsh where residual pools of water remain. Three species were found, *Ceratonereis erythraeensis, Boccardia* sp. and *Capitella capitata.* All these species were represented by one or two individuals.

Mangroves

The mangrove zone is dominated by the grey mangrove *Avicennia marina* var. *australasica* which is the common mangrove on the Central Coast (Fig. 6). Adjoining the salt marsh there is a small number of the river mangrove *Aegiceras corniculatum,* a species which is more abundant in brackish waters. Despite intrusions by the Council garbage tip, mangroves occupy a significant area of Careel Bay (Table 1) and the stand appears to be colonizing the upper part of the *Zostera* zone (Fig. 7). The bases of the mangrove trees and pneumatophores are covered with a tufted red algae. The species has not been determined.

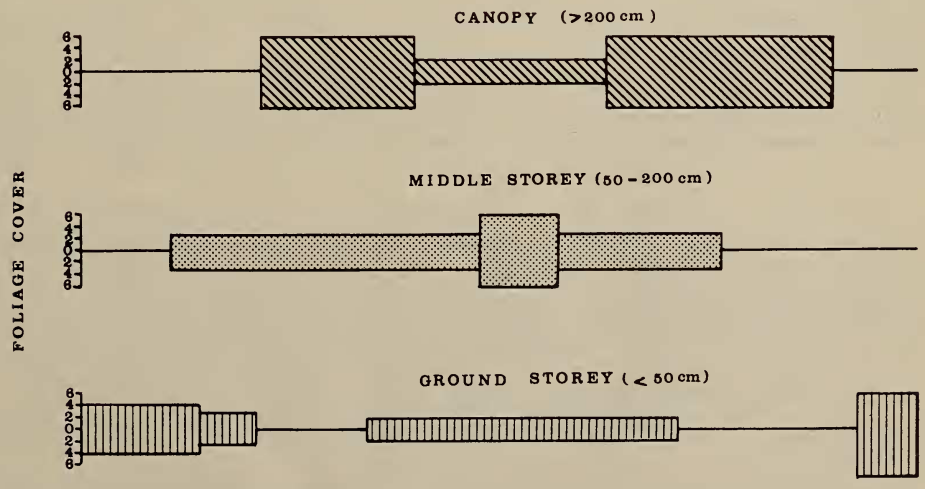


Fig 8. Schematic diagram of the Mangrove community in Careel Bay.

The mangrove zone is inundated on each high tide and the size of an individual tree is closely related to its position in the inter-tidal zone. The best growth of mangroves at Careel Bay occurs immediately adjacent to the *Zostera* flats; that is, just about mid tide level. A transect through the mangroves (represented schematically in Fig. 8) shows that tree height declines behind the first line of trees, with trees being noticeably smaller and more widely spaced in the central portion of the stand and adjacent to the salt marsh. The small size of the trees and the wide spacing of trees in the central portion of the stand may indicate that this part of the stand is higher above low water than areas along the fringe of the stand. Associated with changes in the height of trees and their spacing are changes in the density of foliage cover of the seedling and sapling layers. Throughout the mangrove stand is a layer of seedlings persisting at the two or four leaved stage. The leaves of these seedlings are arranged horizontally to the ground to intercept a maximum amount of the light diffusing through the rather dense canopy layer (Fig. 8) (see Horn, 1972 for a discussion of the adaptive morphology of trees). Whenever there is an opening in the canopy, the seedlings shoot towards the light and a dense middle storey rapidly develops.

TABLE 5

DENSITY DETERMINATIONS OF MOLLUSCS IN THE MANGROVES

Species	Site Nos.					
	1	2	3	4	5	6
Saccostrea cucullata	671	171	307	157	1342	167
Bembicium auratum	125	48	51	73	250	52
Modiolus pulex	5	2	2	3	10	1
Chiazacmea flammea	37	12	23	16	74	15
Unknown bivalve	4	1	2	—	8	1
Calliostoma sp.	3	—	—	—	6	—
Total no. of individuals per m^2	845	234	385	249	1690	236

The marine invertebrate fauna of the mangroves was richer than that found in the salt marsh both in terms of number of species and individuals. This was particularly noticeable among the molluscs where 16 species were recorded. The oyster *Saccostrea cucullata* was abundant on the lower trunks of mangrove trees especially those close to the weed beds and creek. *Littorina scabra* was commonly found grazing on the epibiota on the surfaces of the mangrove leaves. The densities of some of the common molluscs found in this zone are given in Table 5. Though not numerically abundant the pulmonate *Onchidium damelli* was common in this zone.

Crabs were common in the mangroves and several species occur, *Sesarma erythrodactyla, Paragrapsus laevis, Heloecius cordiformis* and *Scylla serrata.* Some

indication of the densities of these crabs observed feeding at night were given in the preceding section on marine invertebrates. The amphipod *Ampithoe* sp. was also common. Odum and Heald (1972) have shown that amphipods are important in the shredding of mangrove leaves. The shredding makes the leaves available to other detritus feeders. A single specimen of *Laomedia healyi* was found on the surface of the mud at low tide during night collecting.

The polychaete fauna of the mangroves was virtually restricted to the channels and creek which flow through the mangroves, *Nereis* (*Hediste*) *diversicolor* and *Nephtys australiensis* were the most common species. The nereid *Neanthes vaalii* was found in the oyster communities at the bases of the mangrove trees. *Zostera*

Between 0.8m above low water to 1.2m depth contour, the shallows of Careel Bay are dominated by the marine angiosperm, *Zostera capricornis* (Fig. 7). *Halophila ovalis* was also present, though during the period of our survey it was not abundant. Among the *Zostera* were the red algae, *Gracilaria verrucosa,* and *Hypnea valentiae* and the brown alga *Dictyota dichotoma.* The algae are seasonal in occurrence and reach a maximum density in late spring and early summer. The blades of *Zostera* commonly supported a well developed epibiota community.

The *Zostera* zone can be conveniently divided into an upper and lower zone (see Fig. 4). The junction of the upper and lower *Zostera* occurs at Indian Spring low water. The lower zone was distingushed by a greater biomass of *Zostera* and the presence of the Sydney cockle, *Anadara trapezia.* The upper zone was characterized by a sparser plant growth and the occurrence of the Hercules club-shell or Sydney whelk *Pyrazus ebeninus.* Biomass measurements were not made in the upper *Zostera.* Though the *Zostera* of the lower zone gave the impression of a fairly uniform density, biomass measurements indicated a rather patchy distribution (mean 80.60 gm/m^2 SD$\pm$ 90.32). Such figures are within the range that McRoy (1970) found. The *Zostera* in the upper zone was noticeably patchy with much bare space. In the lower *Zostera* and in the *Posidonia* zone there were scattered circular spots devoid of plant growth and animal life. The origin of these spots is not known, but may be resting places for rays.

a. *Upper Zostera*

Far greater numbers of species and individuals were present in this zone in comparison to the sandy beach. Polychaetes and molluscs dominated the samples both in terms of numbers of species and individuals.

The dominant polychaete in all samples was *Nephtys australiensis* but in the November samples, large numbers of juvenile *Haploscoloplos* n. sp. were also present (Table 6). Also in November, large numbers of *Nereis* (*Hediste*) *diversicolor* were found although this species was previously only found in small numbers (e.g. February).

The most abundant species of molluscs were *Macoma deltoidalis* and *Nassarius burchardi* which was commonly found grazing on the epibiota of the *Zostera.* In November, many juveniles of *M. deltoidalis* were collected. Similarly numerous juveniles of *Notospisula parva producta* were present in June and November samples. Two juveniles of *Anadara trapezia* were found in February and June but no adults were found in this zone. Many of the other molluscs were present in very few numbers e.g. *Laternula tasmanica, Eumarcia fumigata,* and *Austrocochlea obtusa.*

The crustaceans were represented by more species than in any of the preceding zones, but many species were collected in small numbers (Table 6). The amphipod *Melita* sp. was numerous in two samples collected in November, but absent from most others. Relatively similar numbers of *Macrophthalmus setosus* and *M. crassipes* were found in both the upper and lower *Zostera* zones. The numbers of *M. setosus* increased greatly in June in both zones. In the June and November samples, species A and B were collected (see note in marine invertebrates section). Both these species were more abundant in the lower *Zostera.*

b. *Lower Zostera*

Quantitative samples were collected only in June and November. In February no division of the *Zostera* into upper and lower zone was made and all the samples collected in February were from the upper *Zostera.*

The lower *Zostera* was the richest of all the zones sampled (Table 6) with an average of 14-15 species per sample. Polychaetes dominated this zone. The capitellids *Notomastus hemipodus* and *Barantolla lepte* were particularly abundant. Less common but invariably present were the terebellids, *Lysilla pacifica* and *Rhinothelepus lobatus.* In November large numbers of juvenile *Owenia fusiformis* were present indicating successful breeding had occurred between June and November. The *Zostera* blades were covered in *Spirorbis* sp. but no attempt to quantify them was made. Virtually all the species of polychaetes which were found in the upper *Zostera* also occurred in the lower *Zostera,* but additional species noticeably the terebellids and spionids were restricted to the lower *Zostera.*

The rich mollusc fauna of this zone was characterized by *Macoma deltoidalis, Nassarius burchardi* and *Anadara trapezia.* In June and more notably in November very small specimens (5-8 mm in length) of *A. trapezia* were found. The volume of sediment collected in these quantitative samples 9000cm^3 was insufficient to collect adequate numbers of adults for determination of their relative abundance. Using a quadrat 0.25 m^2 in size, the average density of *A. trapezia* was 8-59/m^2, although there was some evidence of clustering. Within a quadrat anything from 0-6 specimens could be found. The adults range in size from 42-64 mm in height and no obvious year groups could be distinguished (Fig. 9). While collecting *A. trapezia* from 40 quadrats, two specimens of the echinoderm *Astropecten polycanthus* were found.

TABLE 6

SEASONAL DATA FROM SANDY BEACH AND WEED BEDS

(For each species, the mean value and standard deviation of number of animals found in 10 consecutive quantitive samples is given).

	Sandy Beach			*Upper Zostera*			*Lower Zostera*		*Posidonia*		
	Feb.,	June,	Nov.,	Feb.,	June,	Nov.,	June,	Nov.,	Feb.,	June,	Nov.,
Polychaetes											
Paralepidonotus cf ampuliferons							0.2, 0.4				
F. Phyllodocidae							0.1, 0.31				
Syllid sp. 1							0.1, 0.31			0.1, 0.31	
Syllid sp. 2						0.1, 0.31					
Australonereis ehlersi	0.9, 1.41	12.9, 10.0	14.3, 10.0		0.2, 0.63		0.2, 0.63				
Ceratonereis mirabilis		0.1, 0.32	0.1, 0.32	0.1, 0.32			0.3, 0.48	0.1, 0.32			
Nereis (Hediste) diversicolor				0.7, 0.95			0.2, 0.47	0.2, 0.47			
Nephtys australiensis	0.9, 1.0	0.3, 0.48					0.8, 1.03	0.2, 2.26		0.1, 0.32	
Glycera americana							0.2, 0.42		0.4, 0.96	0.7, 0.67	0.1, 0.32
Marphysa sanguinea								0.1, 0.32	0.1, 0.32	0.3, 0.48	0.1, 0.32
Lumbrineris latreilli							0.3, 0.67		0.2, 0.47	0.1, 0.32	0.1, 0.32
Haploscoloplos n. sp.	4.0, 1.9	2.5, 1.78	10.9, 4.24			11.8, 10.2			0.1, 0.32	0.1, 0.32	0.1, 0.32
Naineris sp.									0.9, 0.99	0.2, 0.63	
Phylo sp.							0.1, 0.32			0.4, 0.69	1.1, 1.1
Scoloplos sp.							0.4, 1.27				
Dispio sp.										0.1, 0.32	
Malacoceros sp.										0.1, 0.32	
Polydora sp.			0.2, 0.42				2.1, 2.33			0.6, 0.96	
Prionospio sp.							0.7, 1.25	0.3, 0.67	0.2, 0.42	1.9, 2.3	0.8, 1.03
Magelona sp.	0.3, 0.67										0.1, 0.32
Chaetopterus sp.										0.1, 0.32	
Cirratulus sp.										0.2, 14.94	
Pherusa sp.							0.1, 0.32			0.2, 0.42	
Armandia intermedia					0.4, 1.0	1.3, 1.56	1.9, 1.19	1.6, 1.34	0.2, 0.42	1.0, 1.34	0.6, 0.96
Barantolla lepte	0.1, 0.31	0.3, 0.67			0.1, 0.32	0.1, 0.32					
Capitella capitata	0.1, 0.32								0.2, 0.42	1.2, 1.68	0.3, 0.48
Heteromastus sp.							0.1, 0.32				0.1, 0.32
Mediomastus sp.				0.1, 0.32	2.0, 1.89	0.8, 0.92	7.5, 4.14	5.4, 1.95	2.1, 1.66	0.8, 0.92	1.8, 1.32
Notomastus hemipodus											

	Sandy Beach			*Upper Zostera*			*Lower Zostera*		*Posidonia*		
	Feb.,	June,	Nov.,	Feb.,	June,	Nov.,	June,	Nov.,	Feb.,	June,	Nov.,
Arenicola bombayensis					0.1, 0.32						
Owenia fusiformis		0.1, 0.32		0.5, 0.97	0.5, 0.97	1.3, 1.59	1.0, 1.6	6.8, 6.59	0.1, 0.32	0.4, 0.96	
Amphicteis sp.						0.1, 0.32	0.5, 0.97			0.2, 0.42	
Lysippides sp.									0.2, 0.42		
Samytha sp.							0.2, 0.42				
Lysilla pacifica							1.5, 0.85	1.0, 0.94		0.1, 0.32	0.2, 0.42
Rhinothelepus lobatus							1.9, 1.66	0.4, 0.52		0.2, 0.42	0.2, 0.42
Thelepus setosus									0.1, 0.32		
Pista sp.								0.3, 0.67			
Coelenterates											
Edwardsia sp.						0.4, 0.69					0.1, 0.32
Turbellarian						0.2, 0.42					
Nemerteans											
Heteronemertean	0.1, 0.32		0.2, 0.42		0.2, 0.63	1.3, 1.82	1.2, 1.87	1.0, 1.56	0.3, 0.48	0.4, 0.96	0.1, 0.32
Phoronid								0.8, 0.92			
Crustaceans											
F. Anthuridae										0.1, 0.32	
Cymodoce coronata									0.1, 0.32	0.1, 0.32	
Sphraeromidae sp. A										0.1, 0.32	
Ampithoe sp.							1.0, 1.33	1.1, 1.45	0.1, 0.32	1.4, 1.51	0.9, 1.1
Melita sp.						1.9, 3.78					
Liljeborgia sp.											0.1, 0.32
Urohaustorius sp.			0.1, 0.32							0.3, 0.48	
Penaeus plebejus		0.2, 0.42		0.3, 0.48		0.1, 0.32		1.1, 2.60	0.1, 0.32	0.1, 0.32	
Penaeus sp.					0.1, 0.32		0.2, 0.42				
Macrobrachium intermedius											0.2, 0.42
Alpheus euphrosyne				0.1, 0.32	0.3, 0.48	0.3, 0.48			0.3, 0.67	0.5, 0.84	0.5, 0.97
Alpheus sp. B							0.1, 0.32			0.2, 0.63	
Hippolyte tenuirostris										0.1, 0.32	
Callianassa sp.							0.3, 0.48		0.1, 0.32	0.1, 0.32	0.2, 0.42
Halicarcinus ovatus											0.1, 0.32
Portunus pelagicus							0.1, 0.32				
Thalamita sima				0.1, 0.32						0.1, 0.32	
Heteropanope serratifrons					0.1, 0.32	0.1, 0.32	0.2, 0.47	0.1, 0.32			0.1, 0.32
Macrophthalmus setosus					3.1, 1.97	0.1, 0.32	0.3, 0.48	2.0, 1.33			
Macrophthalmus crassipes				0.4, 0.52	0.5, 0.97	1.4, 2.22	0.1, 0.32	0.8, 1.32			
Macrophthalmus cf *punctulatus*	0.4, 1.26										
Macrophthalmus sp. 1		0.2, 0.63									
Species A					0.6, 0.70	0.3, 0.48	1.2, 1.55	1.4, 0.7			

	Sandy Beach			*Upper Zostera*			*Lower Zostera*		*Posidonia*		
	Feb.,	June,	Nov.,	Feb.,	June,	Nov.,	June,	Nov.,	Feb.,	June,	Nov.,
Species B			0.1, 0.32		0.5, 0.97	0.1, 0.32	0.3, 0.48	1.8, 1.03			
Australoplax tridentata									0.6, 1.26		
Mictyris longicarpus	0.8, 1.03	2.0, 1.63	9.8, 4.47								
Molluscs											
Anadara trapezia				0.1, 0.32	0.1, 0.32		0.5, 0.52	0.5, 0.71			0.1, 0.32
Xenostrobus securis							0.1, 0.32				
Laternula tasmanica				0.3, 0.67	1.6, 1.42		0.2, 0.63	0.8, 0.78			
Cavatidens omissa	0.1, 0.32			0.2, 0.42		0.4, 0.69	2.0, 1.94	1.1, 1.52	0.3, 0.67		0.2, 0.42
Mysella sp.					0.4, 0.69	0.1, 0.32	0.1, 0.32			0.2, 0.63	
Eumarcia fumigata	0.1, 0.32	0.1, 0.32				0.1, 0.32					
Tapes watlingi							0.3, 0.67	0.1, 0.32			
Notospisula parva producta	0.1, 0.32	10.1, 16.10			1.3, 2.12	2.6, 3.02	0.3, 0.67	0.1, 0.32		0.2, 0.42	0.1, 0.32
Florisarka onuphria		0.1, 0.32									
Macoma deltoidalis	0.1, 0.32			3.5, 1.9	3.1, 1.52	4.5, 3.41	3.5, 2.36	10.1, 6.67	0.6, 1.26	0.5, 0.52	0.2, 0.42
Austrocochlea obtusa				0.6, 1.26		0.5, 0.84					
Calliostome australe										1.0, 1.41	1.8, 2.14
Liota sp.					0.1, 0.32	0.1, 0.32	0.1, 0.32				
Diala sp.											0.1, 0.32
Cacozeliana lacertina	0.2, 0.42					0.1, 0.32	0.5, 1.08	0.9, 0.87	0.1, 0.32	2.6, 1.78	4.8, 2.34
Pyrazus ebenensis					0.1, 0.32	0.1, 0.32					
Epitonium sp.						0.1, 0.32					
Conuber sordidum						0.1, 0.32	0.1, 0.32				
Conuber sp.		0.1, 0.32									
Nassarius burchardi		0.1, 0.32		6.9, 4.93	3.7, 2.2	1.4, 1.71	6.3, 4.99	9.0, 11.6	0.1, 0.32	0.5, 1.58	0.3, 0.48
Bedeva hanleyi	0.63, 0.2									0.1, 0.32	
Salinator sp.	0.3, 0.67										
F. Doridídae				0.1, 0.32							
Haminoea wallissi				1.5, 1.26	0.1, 0.32		0.1, 0.32				
Fish											
Centropogon australis										0.1, 0.32	
Rhabdosargus sarba					0.1, 0.32	0.1, 0.32				0.1, 0.32	
Gerres ovatus				0.2, 0.42							
Bathygobius kreffti							0.1, 0.32				0.1, 0.32
Favonigobius lateralis				0.5, 0.84							
Lizagobius olorum				0.2, 0.42							
Total Nos. of individuals	96	290	347	314	293	469	395	512	75	184	156
Total Nos. of species	16	15	8	19	24	31	46	27	23	42	31

In comparison with the molluscs and polychaetes, crustaceans were poorly represented in this zone. The amphipod *Ampithoe* sp. and the crabs *Macrophthalmus setosus* and species A and B were the most abundant species.

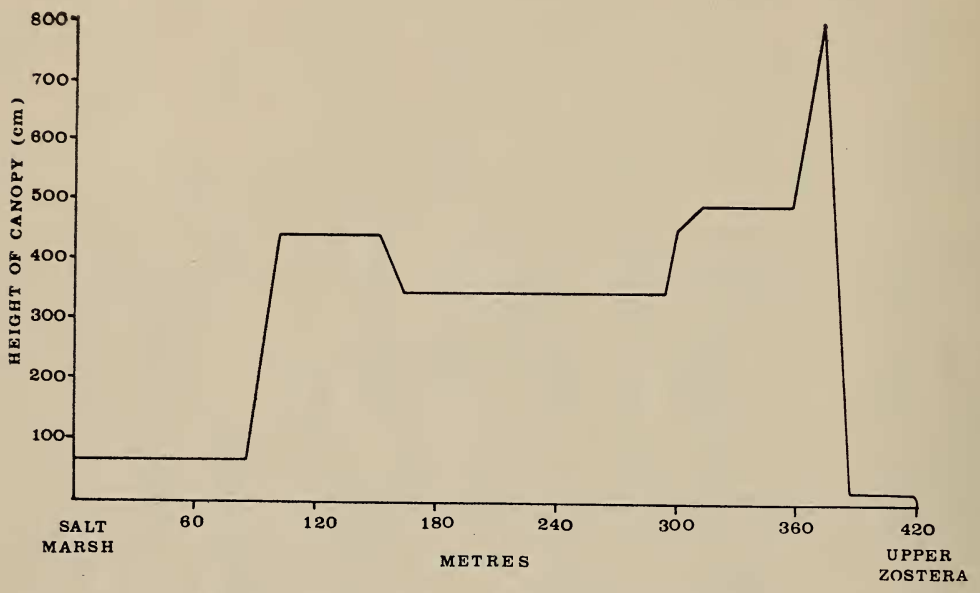


Fig. 9. Size distribution of the Sydney Cockle *Anadara trapezia* at Careel Bay.

Posidonia

The *Posidonia* flats extend from 1.2m depth contour to a depth of approximately 11m. The marine angiosperm, *Posidonia australis,* dominates this zone and other plant life is absent or epiphytic. Collections of epiphytes on the leaves of *Posidonia* were made and sorted, but these have not yet been identified. Polychaetes and small crustaceans were well represented in these collections. From 11m, plant growth becomes increasingly sparse and gives way to a sandy sea floor. The depth to which *Posidonia* can grow is determined by water clarity and its occurrence in 10-12 m of water in Careel Bay attest to the lack of turbidity or of the intrusion of Hawkesbury River water. Biomass measures in the *Posidonia* zone showed less variation than those made in the lower *Zostera* ($287 g/m^2$ - SD$\pm$57.88.

The *Posidonia* zone had a large number of species but relatively few individuals in any one sample in comparison to the lower *Zostera* zone (Table 6). This was particularly true of polychaetes where many species were represented only by one or two individuals e.g. *Armandia intermedia, Mediomastus* sp.,

Chaetopterus sp. and *Cirratulus* sp. This zone had some very large species of polychaetes present, *Glycera americana, Marphysa sanguinea* and *Chaetopterus* sp. and it is possible that the biomass of polychaetes would be greater in the *Posidonia* than in the lower *Zostera,* even though far fewer species are present.

Molluscs were poorly represented in this zone and the only numerically abundant species was *Cacozeliana lacertina.* Similarly crustaceans were poorly represented in the quantitative samples but this was probably a reflection on sampling techniques. As in the lower *Zostera* the amphipod *Ampithoe* sp. was common.

DISCUSSION

Without measuring energy flow, comments on the ecology of Careel Bay and its importance to the total estuary must necessarily be speculative. However, to judge by the number of species, the presence of many juvenile fish and the total standing biomass of plants and animals in Careel Bay, there is a significant production of organic matter in the salt marsh, mangrove and sea grass habitats. The invertebrate fauna of the salt marsh, mangrove and sea grass habitats is dominated by detritus feeding animals. It appears similar to the mangrove-invertebrate system described in detail for Florida by Odum and Heald (1972). Organic matter in the form of leaves and fruits enter the estuary where they are attacked by bacteria, fungi and small invertebrates. These break down the material to a size which can be ingested by other detritus feeders. Through a long series of steps in which the original matter of a mangrove leaf may be reingested many times, the complex molecular structure of the leaf is broken down and its energy released. The detritus feeders are in turn fed upon by predators. A later paper will discuss the possible reasons for the zonation of animals in the Bay and the potential food web operating both within and between the zones.

Our results have shown that Careel Bay is a very rich area in terms of numbers of species present. A similar ecological and geographical area to Careel Bay is Towra Point in Botany Bay which has been sampled by Weate (pers. comm.) using the same quantitative methods used in Careel Bay. She found in June, 30 species of animals in the *Zostera* and 13 species in the *Posidonia* weed beds. By comparison in Careel Bay, 51 and 54 species were found respectively in the *Zostera* and *Posidonia* weed beds. The reasons for the greater number of species being present in Careel Bay are not fully understood but parts of Botany Bay are heavily industrialized and extensive dredging occurs. Dredging must have deleterious effects on pelagic larvae which pass through the dredge. The majority of animals found in estuarine situations have pelagic larvae.

We have looked at other areas in the Hawkesbury-Broken Bay system, notably Patonga Creek (Broken Bay), Spectacle Island (Hawkesbury River) and Riley's Island (Brisbane Waters), which have many fewer species compared to Careel

Bay. However, individual species (e.g. *Macrophthalmus setosus, Mictyris longicarpus* and *Callianassa* sp. achieve considerably greater population densities on the tidal flats of Patonga than at Careel Bay.

One of us (Hutchings, 1974) has sampled in Wallis Lake, N.S.W. This is a coastal lagoon continually open to the sea but at times it receives large volumes of freshwater. A total of 32 species of polychaetes were found along the eastern shores of the lake in the weed beds of *Zostera* and *Halophila.* All the species present in Wallis Lake are also present in Careel Bay. Weate (pers. comm.) has sampled in the adjacent Smiths Lake, which is often closed to the sea. Sampling in December, using a hand operated corer, a total of 28 animal species were found. Similarly, surveys conducted by the N.S.W. Division of the Australian Littoral Society have shown that the numbers of species of animals decreases progressively up the estuary as the salinity falls. All the areas mentioned above have some species in common, e.g. Polychaetes, *Australonereis ehlersi, Nereis (Hediste) diversicolor, Marphysa sanguinea, Haploscoloplos* sp. and *Notomastus hemipodus;* Molluscs, *Nassarius jonasi, Pyrazus ebeninus, Macoma deltoidalis;* Crustaceans, *Paragrapsus laevis, Macrophthalmus* sp. and *Halicarcinus ovatus.*

It appears that Careel Bay represents the richest estuarine area yet sampled in N.S.W. This can partially be attributed to its almost totally marine situation, but other factors may be involved. We hope to elucidate these other factors by continuing to survey wetland areas on the N.S.W. coast.

It is very difficult to compare our work with studies done overseas as sampling techniques vary widely, but some comments can be made on geographically similar temperate areas. Day (1967) working on South African estuaries has found that estuaries vary in the richness of their fauna and he attributes this to the amount of freshwater entering the estuary and to the clarity of the water. The richest area comparable to Careel Bay that he has studied is the Knysna estuary which has clear water, allowing dense beds of sea grasses to flourish. Only small quantities of fresh water enter the river throughout the year. Other estuaries in the same temperate region are subjected to flooding and have eroding river banks, reducing clarity of water, hence weed growth is diminished and far fewer species of animals are present. Day (1967) also suggests that a wide opening to the sea (such as Careel Bay has) is important in maintaining water exchange and tidal movement. Day has recorded 350 species from Knysna estuary including, 69 polychaetes, 12 crabs, and 40 fishes. Considering that Careel Bay in comparison is a very small area and only the larger components of the fauna have been collected, the number of species of polychaetes is of the same order of magnitude. The number of species of polychaetes (at present 46) seems certain to increase, once the epibiota of the *Posidonia* and *Zostera* is analysed. Careel Bay is thus similar in species diversity to temperate South African estuaries and is the richest wetland area yet sampled in New South Wales.

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REFERENCES

CLARK, R. B. (1961). The origin and formation of the heteronereis. Biol. Rev. *36,* 199-227.

CLARK, R. B. (1965). Endocrinology and the Reproductive Biology of Polychaetes. Oceanogr. mar. Biol. Ann. Rev. *3,* 211-255.

CLARKE, L. & N. HANNON (1967). The mangrove swamp and salt marsh communities of the Sydney district. I. Vegetation, soils and climate. J. Ecol. *55,* 753-772.

CLARKE, L. & N. HANNON (1969). The mangrove swamp and salt marsh communities of the Sydney district. II. The holocoenotic complex with particular reference to physiography. J. Ecol. *57,* 213-234.

CLARKE, L. & N. HANNON (1970). The mangrove swamp and salt marsh communities of the Sydney district. III. Plant growth in relation to salinity and water logging. J. Ecol. *58,* 351-370.

CLARKE, L. & N. HANNON (1971). The mangrove swamp and salt marsh communities of the Sydney district. IV. The significance of species interaction. J. Ecol. *59,* 535-554.

COLLINS, W. I. (1921). On mangrove and salt marsh vegetation near Sydney, N.S.W. with special reference to Cabbage Tree Creek, Port Hacking. Proc. Linn. Soc. N.S.W. *46,* 376-392.

DAY, J. H. (1967). The Biology of Knysna estuary, South Africa in "Estuaries", Amer. Assoc. Advan. Sci. Publ. *83,* 397-407.

DAKIN, W. J., I. BENNETT & E. POPE (1969). Australian Seashores. Angus and Robertson, Sydney, 372 pp.

DALES, R. P. (1950). The reproduction and larval development of *Nereis diversicolor.* J. mar. biol. Ass. *29,* 321-360.

DALES, R. P. (1955). Feeding and digestion in terebellid polychaetes. J. mar. biol. Ass. *34,* 55-79.

GOODRICK, G. N. (1970). A survey of the wetlands of coastal N.S.W. C.S.I.R.O. Div. of Wildlife Res. Technical Memo. no. 5. Sept.

HAMILTON, A. A. (1919). An ecological study of the salt marsh vegetation in the Port Jackson District. Proc. Linn. Soc. N.S.W. *44,* 463-513.

HARTMAN, O. (1954). Australian Nereidae. Trans. R. Soc. S. Aust. 77, 1-41.

HATTERSLEY, R. T., P. A. HUTCHINGS & H. F. RECHER (1973). Careel Bay, Pittwater, N.S.W. Development Proposals, Environmental Studies. Univ. N.S.W. Water Research Laboratory, Tech. Rep. No. 73/6, 35 pp.

HORN, H. S. (1971). The Adaptive Geometry of Trees. Monographs in Population Biology. 3. Princeton University Press, 133 pp.

HUTCHINGS, P. A. (1974). The polychaeta of Wallis Lake, N.S.W. Proc. Linn. Soc. N.S.W. *98,* 175-195.

KRATOCHVIL, M., N. J. HANNON & L. D. CLARKE (1972). Mangrove swamp and salt marsh communities in Southern Australia. Proc. Linn. Soc. N.S.W. *97*, 262-275.

LONGBOTTOM, M. R. (1968). Nutritional factors affecting the distribution of *Arenicola marina* L. Ph.D. Thesis, University of London.

LYFORD, J. & H. PLINNEY (1968). Primary Productivity and community Structure of an Estuarine Impoundment. Ecology, *49*, 854-866.

MACNAE, W. (1966). Mangroves in eastern and southern Australia. Aust. J. Bot. *14*, 67-104.

MACNAE, W. (1967). Zonation within mangroves associated with estuaries in North Queensland. In "Estuaries" Amer. Assoc. Advan. Sci. Publ. *83*, 432-441.

McROY, C. P. (1970). Standing Stocks and other Features of Eelgrass (*Zostera marina*) Populations on the coast of Alaska. J. Fish. Res. Bd. Can. *27*, 1811-1821.

NEWELL, R. (1965). The role of detritus in the nutrition of two marine deposit-feeders, the prosobranch *Hydrobia ulvae* and the bivalve *Macoma balthica*. Proc. zool. Soc. Lond. *144*, 25-45.

ODUM, E. P. (1961). The Role of Tidal Marshes in Estuarine Production. The Conservationist June-July 1961, 12-15.

ODUM, E. P. & A. A. DE LA CRUZ (1967). Particulate organic detritus in a Georgia salt marsh estuarine ecosystem. In "Estuaries". Amer. Assoc. Adv. Sci. Publ. *83*, 383-388.

ODUM, W. E. & E. J. HEALD (1972). Trophic analysis of an estuarine mangrove community. Bull. Mar. Sci. *22*, 671-738.

SCHROEDER, P. C. (1968). On the life history of *Nereis grubei* (Kinberg), a Polychaete Annelid from California. Pacif. Sci. *22*, 476-481.

SNELLING, B. (1959). The distribution of intertidal crabs in the Brisbane River. Aust. J. Mar. Freshwat. Res. *10*, 67-83.

APPENDIX I

Insects Recorded from Careel Bay, N.S.W.

Diptera

Family:
Tephritidae
Euphranta n. sp.
Dacus (*Strumeta*) *tryoni*

Family:
Platystomatidae
Rivellia n. sp.

Family:
Lauxaniidae
Panurgopsis n. sp.
Prochaetops n. sp.
Chilocryptus sp.
Trigonometopsis n. sp.
Trigonometopus sp.

Family:
Carnidae
Australimyza sp.

Family:
Milichiidae
Desmometopa sp.

Family:
Cryptochetidae
Cryptochetum sp.
Family:
Tethinidae
Dasyrhicnoessa sp.
Family:
Canaceidae
Canace sp.
Xanthocanace sp.
Family:
Chloropidae
Merodonta sp.—Southern Record for genera
Pemphigonotus sp.—Southern Record for genera

Lepidoptera
Family:
Oxychirotidae
Cenoloba obliteratis

Hymenoptera
Family:
Ichneumonidae
Echthromorpha intricatoria Fabricius
Lissopimpla excelsa Costa
Netelia producta Brullé
Eriborus sp. (parasite of *Coenoloba* sp.)
Sphinctus sp.
Family:
Braconidae
Priaspis sp.
Chelonus unimaculatus Szepligeti—first record since original description
Chelonus australiensis Szepligeti—first record since original description
Phanerotoma australiensis Ashmead
Apanteles ruficrus Haliday
Microgaster sp.
Opius sp. (parasitic on *Euphranta* sp.)
Family:
Evaniidae
Evania appendigaster Linné
Family:
Sphecidae
Sphex fumipennis
Sphex globosus
Sceliphron laetum
Isodontia nigella
Isodontia sp.
Larra sp.
Pison sp.
Family:
Tiphiidae
Diamma bicolor
Family:
Vespidae
Polistes tasmaniensis

Family:

Apidae
Apis mellifera
Many of these insects which have been identified only to genus, are new species.

APPENDIX II

The following fishes were collected in Careel Bay at various times of the year, and in the Hawkesbury River estuary on November 23, 1972, at low tide by 20' seine. The following are the individual collecting localities: (1) beach at eastern side of Dangar Island; (2) Fisherman's Beach, Cowan Creek, Broken Bay; (3) Head of Jerusalem Bay, Cowan Creek; (4) Careel Bay. The numbers after the species refer to the various localities.

Family Urolophidae-stingrays
Urolophus testaceus 2
Family Clupeidae—sardines, herrings, sprats
Hyperolophus vittatus 2
Family Syngnathidae—pipefishes and seahorses
Hippocampus sp. 4
Stigmatophora nigra 2, 4
Urocampus carinirostris 1, 3
Family Hemiramphidae—garfishes
Hyporhamphus ardelio 2
Family Atherinidae—hardyheads and blue eyes
Pranesus ogilbyi 2
Taeniomembras microstomus 3
Pseudomugil signifer 3
Family Scorpaenidae—fortesques and red perches
Centropogon australis 1, 2, 3, 4
Family Centropomidae—glass perches
Velambassis jacksoniensis 1, 2, 3, 4
Family Platycephalidae—flatheads
Platycephalus sp. juv. 2
Family Enoplosidae—old wives
Enoplosus armatus 2
Family Theraponidae—grunters
Pelates sexlineatus 1, 3, 4
Family Carangidae
Caranx sp. 4.
Family Gerridae—silver biddies
Gerres ovatus 3, 4
Family Scorpidae—luderick, sweep
Girella tricuspidata 3, 4
Family Sparidae—bream, tarwhine, snapper
Acanthopagrus australis 2, 3
Rhabdosargus sarba 2, 3, 4
Family Mullidae
Upeneichthys tragula 4
Family Mugilidae—mullet
Myxus elongatus 1, 2, 3
Family Pomatomidae—tailor
Pomatomus saltatrix 2
Family Clinidae
Cristiceps australis 4
Family Gobiidae—gobies
Arenigobius frenatus 1, 3, 4
Bathygobius kreffti 1, 2, 3, 4
Favonigobius exquisitus 3, 4
Lizagobius olorum 3, 4
Nesogobius pulchellus 4
Redigobius macrostomus 1, 3
Family Bothidae—left eyed flounders
Pseudorhombus jenynsii 1
Family Balistidae
Meuschenia skotlower 4
Family Aluteridae—leatherjackets
Navodon skottowei 2, 3
Monocanthus macrolepis 4
Family Tetraodontidae—toados
Torquigener hamiltoni 2, 3, 4
Family Diodontidae—porcupine fishes
Dicotylichthys myersi 2, 3
Diodon punctulatus 4